Image Cover Sheet

TITLE

COMPUTATIONAL FLUID DYNAMIC ANALYSIS OF THE BASE CAVITY INTERACTIONS OF THE CAN-4 RESEARCH PROJECTILE

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAR 1997**	2. REPORT TYPE	3. DATES COVERED
4. TITLE AND SUBTITLE **Computational Fluid Dynamic Analysis of the Base Cavity Interactions of the CAN-4 Research Projectile**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Defence R&D Canada - Valcartier,2459 Pie-XI Blvd North,Quebec (Quebec) G3J 1X5 Canada, ,**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The aerodynamics of a cone-cylinder-flare projectile at high supersonic speeds has been investigated through computational means, and the results compared with existing experimental results from DREV's aeroballistic range. Aerodynamic coefficients, base pressure surveys, base flow visualization and shock patterns over the projectile were investigated for a Mach number range of 3.5 to 5.75. A goal of this investigation was the numerical study of the effects of a base cavity on the aerodynamic behavior of this projectile. Quantitative and qualitative information was accurately modelled by the CFD code as indicated by correlations between experimental and numerical values. The results seem to indicate an independence between the aerodynamic coefficients (aerodynamic coefficients constitute some of the major parameters of this study) and the presence of a base cavity for this particular configuration.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**35**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

UNCLASSIFIED

DEFENCE RESEARCH ESTABLISHMENT
CENTRE DE RECHERCHES POUR LA DÉFENSE
VALCARTIER, QUÉBEC

DREV - TM - 9620
Unlimited Distribution / Distribution illimitée

COMPUTATIONAL FLUID DYNAMIC ANALYSIS OF THE BASE CAVITY INTERACTIONS OF THE CAN-4 RESEARCH PROJECTILE

by

E. Y. Fournier and A. D. Dupuis

March/mars 1997

Approved by / approuvé par

Chief Scientist / Scientifique en chef

11 Feb '97

Date

SANS CLASSIFICATION

ABSTRACT

The aerodynamics of a cone-cylinder-flare projectile at high supersonic speeds has been investigated through computational means, and the results compared with existing experimental results from DREV's aeroballistic range. Aerodynamic coefficients, base pressure surveys, base flow visualization and shock patterns over the projectile were investigated for a Mach number range of 3.5 to 5.75. A goal of this investigation was the numerical study of the effects of a base cavity on the aerodynamic behavior of this projectile. Quantitative and qualitative information was accurately modelled by the CFD code as indicated by correlations between experimental and numerical values. The results seem to indicate an independence between the aerodynamic coefficients (aerodynamic coefficients constitute some of the major parameters of this study) and the presence of a base cavity for this particular configuration.

RÉSUMÉ

Un projectile de recherche utilisé dans les hautes vitesses supersoniques et de forme cone-cylindre-jupe a été étudié à partir de codes numériques et les résultats ont été comparés aux résultats expérimentaux provenant d'essais dans le corridor aérobalistique du CRDV. L'étude couvre les domaines des coefficients aérodynamiques, de la pression de base, de la visualisation de l'écoulement à la base, ainsi que de la structure de l'écoulement et des ondes de choc pour une plage de nombres de Mach de 3.5 à 5.75. L'analyse de l'effet d'une cavité à la base de ce projectile constitue un autre des buts de cette étude. De l'information quantitative et qualitative a été modélisée avec précision par le code numérique. La comparaison entre les résultats expérimentaux et numériques semblent indiquer une indépendance entre les coefficients aérodynamiques et la présence d'une cavité à la base du projectile pour cette configuration particulière.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Many tube-launched projectiles have some form of cavity in their base. The aerodynamic characteristics and stability parameters of such projectiles are not fully understood at the velocities of current weapon systems. As velocities increase, with novel gun technologies, this lack of knowledge will only be exacerbated. Consequently, to develop the next generation of tube launched projectiles, it is imperative that their aerodynamic characteristics and stability parameters be fully understood at speeds between Mach 5 and 8.

In order to better understand these phenomena, Defence Research Establishment, Valcartier (DREV) has been involved in a research project to study the flight dynamic, aerodynamic, and aero-thermal properties of cone-cylinder-flare hypersonic configurations up to Mach 7. The overall research program consists in conducting aeroballistic range testing of several configurations to determine their aerodynamic coefficients and stability derivatives, conduct outdoor firings to measure temperature in flight, and participate in collaborative work with the Defence Research Agency, Fort Halstead, England. The presence of a base cavity in some of these projectiles has provided the impetus for further investigations. In an effort to better understand the physical phenomena associated with this type of flow, numerical (CFD) analyses of some of these configurations have been performed as well.

This numerical study of the effects of a base cavity on a projectile, and on its aerodynamic characteristics, has been performed to produce an overall understanding of the flow for these flight conditions, and for this specific design. It also provided valuable information to DND on the potential of this type of projectile in future anti-armour weapons. In turn, this allowed DREV to exchange aerodynamic and aerothermal information about the flight behavior of hypersonic projectiles with other TTCP members.

NOMENCLATURE

C_X	drag coefficient
C_{XB}	base component of drag coefficient
$C_{N\alpha}$	normal force coefficient slope
$C_{M\alpha}$	pitching moment coefficient slope
d	projectile body diameter (m)
M	freestream Mach number
P	pressure (Pa)
Re_L	Reynolds number (based on projectile length)
T	temperature (K)
ρ	density (kg/m^3)

1.0 INTRODUCTION

Many actual and future configurations of projectiles have some form of base cavity. The aerodynamic characteristics and stability parameters associated with this type of vehicle have not always been completely understood in current and future speed regimes. However, this type of aerodynamic information will have to be known and understood for the next generation of kinetic energy penetrators, at extreme speed regimes (Mach 4 - 8), before being used in any development phase.

In order to better understand these phenomena, Defence Research Establishment, Valcartier (DREV) has been involved in a research project to study the flight dynamic, aerodynamic, and aero-thermal properties of cone-cylinder-flare hypersonic configurations up to Mach 7. The overall research program consists in conducting aeroballistic range testing of several configurations to determine their aerodynamic coefficients and stability derivatives, conduct outdoor firings to measure temperature in flight, and participate in collaborative work with the Defence Research Agency, Fort Halstead, England. The presence of a base cavity in some of these projectiles has provided the impetus for further investigations. In an effort to better understand the physical phenomena associated with this type of flow, numerical (CFD) analyses of some of these configurations have been performed as well.

This document describes the numerical analysis of the aerodynamic characteristics of one of the configurations designed for experimental testing, and compares the results of this analysis with existing experimental results. The numerical study of the effects of a base cavity on the projectile aerodynamic characteristics has been performed to produce an overall understanding of the flow for these flight conditions and for this specific design. This work was conducted as part of a joint cooperative project between Canada and the UK, under the auspices of TTCP-WTP-2, to study the aerodynamic characteristics and aeroheating aspects of several configurations at hypersonic speeds. It was conducted at Defence Research Establishment Valcartier (DREV) between July 1995 and May 1996, under Project 2EA19 - Hypersonic Flight.

2.0 BACKGROUND

The structures and characteristics of the near and far wakes of supersonic vehicles are known to comprise extremely complex flow patterns, including subsonic recirculations, separated regions, secondary shocks, and extreme fluctuations in pressure, velocity, density and temperature. The presence of these flow patterns constitutes a very demanding scenario for any experimental or numerical resolution techniques. A schematic representation of the different flow patterns behind a moving body at supersonic speed is presented in Fig. 1.

This schematic diagram shows the approaching supersonic flow separating at the base corner, and the free shear layer forming in the wake. An expansion fan affects the flow has it passes the base corner. The flow is then realigned by a recompression shock downstream of the base, which finally leads to the trailing wake formation. A rear stagnation point (reattachment area) also develops upstream of the trailing shock position. A low pressure region is formed immediately downstream of the base which is characterized by a low speed recirculating flow region. This recirculation region is the principal subject of the present study, with its effects on the general aerodynamic parameters of this body.

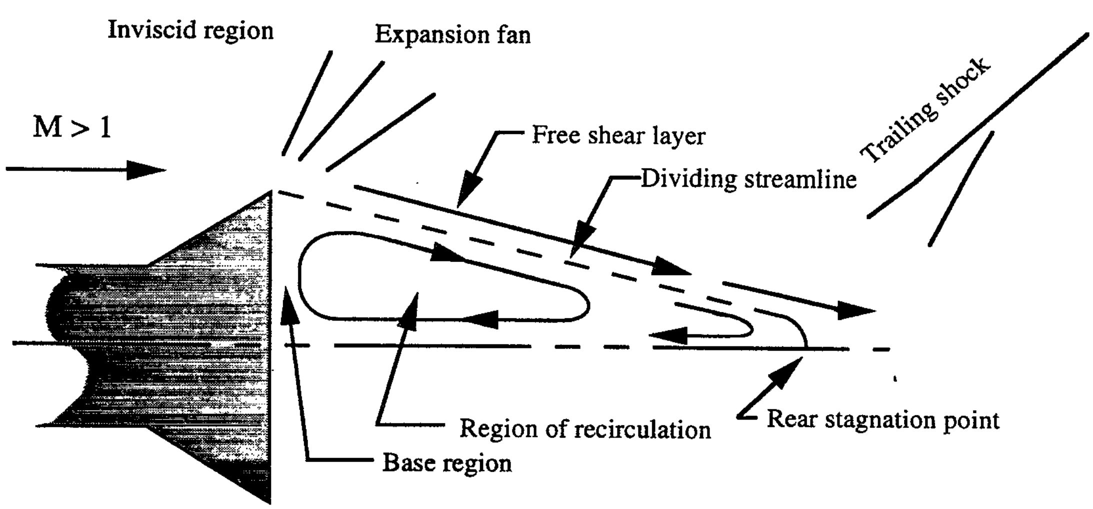

FIGURE 1 - Wake of a supersonic vehicle

Results by Celmins (Ref. 1), using a configuration somewhat different from the model used in the present study, showed a large variation (50%) in the value of $C_{M\alpha}$ between the cases with and without base cavities, but no significant effects on the drag coefficient. The same conclusion (about the effect of a cavity on the drag coefficient) was supported by Compton (Ref. 2) and Nash *et al.* (Ref.3). However, a recent report by Sahu (Ref. 4) shows a significant decrease in base drag, and total drag, when testing projectiles with a base cavity. All the models of Refs. 1 - 4 were different from the CAN-4 projectile.

3.0 PROJECTILE CONFIGURATION

The projectile under investigation, CAN-4, is shown in Fig. 2. It consists of a 1.9 calibre flare base type, and was designed to obtain a centre of gravity at 2.85 calibres from the nose (with the present cavity). The nose was conical with a short cylindrical body section. The nominal diameter of the model was 18 mm. The overall l/d of this configuration was 5.84. Two types of the model were used in the experimental firings. The first type is shown in Fig. 2. The second type was a projectile without a base cavity. It had a pressed fitted disc on the aft end to close the existing cavity.

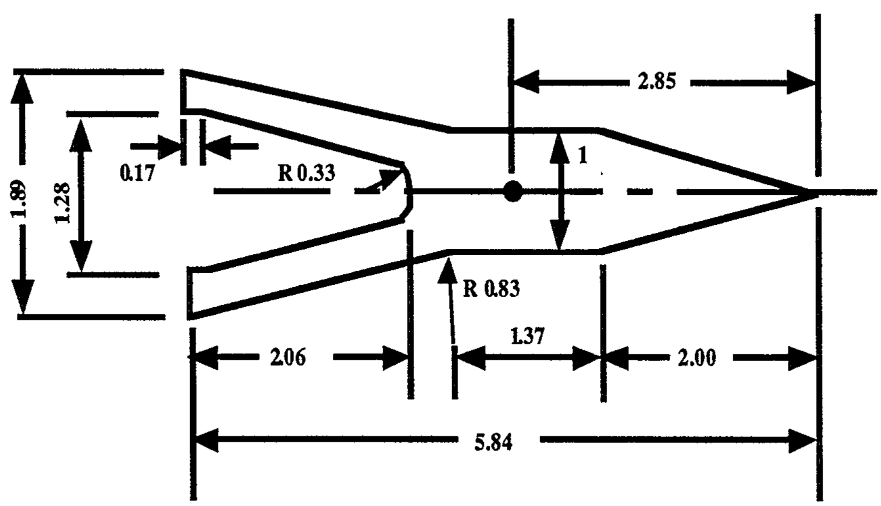

FIGURE 2 - Schematic of the CAN-4 projectile with a deep base cavity (all dimensions: calibres)

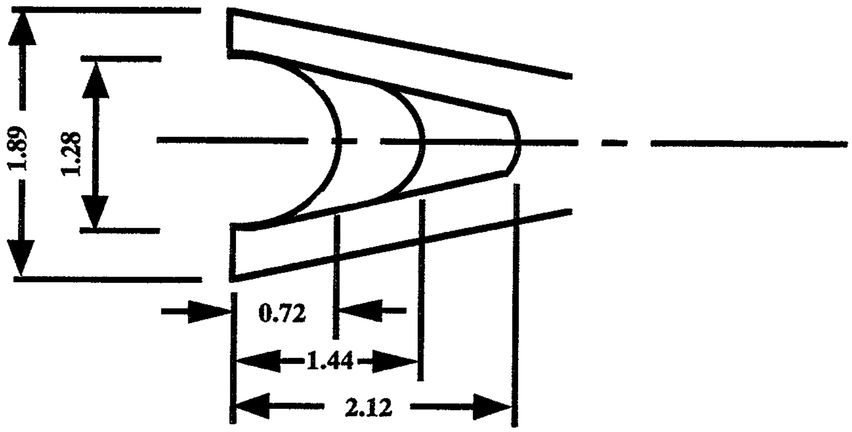

FIGURE 3 - Schematic diagram of base cavity openings (CFD models)

The dimensions of the CFD models were identical to the experimental projectile. However, three different cavity depths were also investigated. The different cavity depths were produced by moving the end wall of the cavity towards the base of the projectile, while keeping the opening of the cavity on the base plane constant (constant opening area), as shown in Fig. 3.

4.0 PROCEDURES

The aerodynamic information on this projectile was generated from two distinct sources, one numerical and the other experimental. Firstly, a CFD code was employed to numerically obtain the required aerodynamic information about this projectile. Computed results show the quantitative and qualitative details of the base flow structure. Base pressure surveys, base flow visualization, and shock patterns over this projectile were numerically investigated. Additionally, several aerodynamic coefficients were obtained by integrating surface pressures and viscous drag over the entire surface of the body (including the base region), and resolving in the appropriate directions to produce the required coefficients, to allow comparisons with existing experimental results. Secondly, the experimental results were generated through firings at Mach numbers as high as 5.75, in the DREV aeroballistic range (Ref. 5).

4.1 Aeroballistic Range

The facility used in the experimental part of the analysis is the DREV aeroballistic range (A/B range). It is used to examine the exterior ballistics of various free-flight configurations, and consists of a gun bay, a control room, and the instrumented range. This range comprises three Schlieren stations followed by 54 orthogonal shadowgraph stations over a range of approximately 260 m (Ref. 6). Ballistic synchro cameras were also employed to provide information on the launch characteristics. The DREV aeroballistic range has a cross sectional area of 6.1 x 6.1m and is temperature and humidity controlled (Fig. 4). Nominal operating conditions are 20°C and 45% relative humidity. For this experiment, flight Reynolds numbers ranged from as high as $Re_L = 1.7 \times 10^7$ at launch, to as low as 5.0×10^6 towards the end of the flight. These Reynolds numbers are sufficiently high that a fully turbulent boundary layer flow had developed along the body. The analysis of the aeroballistic coefficients was carried out at DREV using the Ballistic Range Data Analysis System, BARDAS (Ref. 7). The complete analysis of the test programme can be found in Ref. 8. Figure 5 shows a shadowgraph picture of the CAN-4 configuration at Mach number 5.75 taken in the aeroballistic range (Ref. 5). Shock wave patterns developing of the body are easily identifiable, and a good representation of the turbulence present in the wake can also be seen.

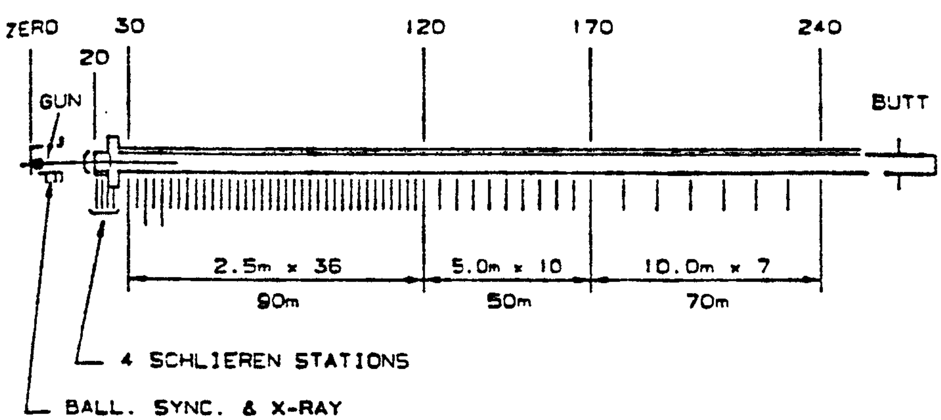

FIGURE 4 - Aeroballistic range photographic station spacing

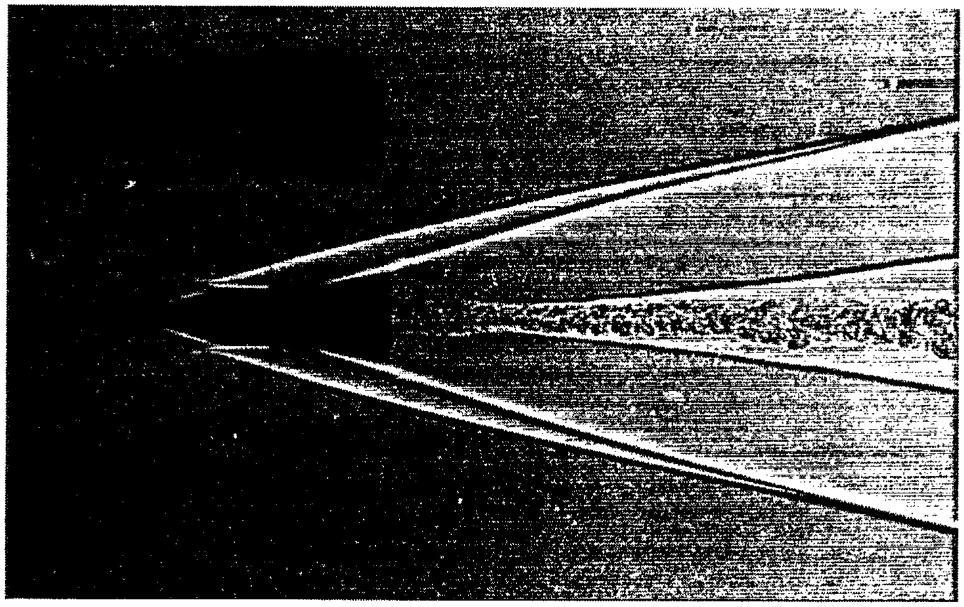

FIGURE 5 - Shadowgraph of the CAN-4 configuration at Mach 5.75

4.2 Computational Fluid Dynamic Code

The code used by DREV is the TASCflow[1] Navier-Stokes code developed by Advanced Scientific Computing Ltd (Ref. 9). This code is a fully implicit, finite volume method with a flux element based discretization of geometry that can utilize various numerical upwind schemes to ensure the global conservation of mass, continuity, momentum, and energy. It generates a general non-orthogonal, structured, boundary fitted grid. For this study, a modified linear profile scheme was used, with both laminar and turbulent cases. For the turbulent cases, a standard k-ε turbulence model with wall functions was used to evaluate the Reynolds stresses and thermal diffusion.

The following two figures show various aspects of the computational domains. Figure 6 shows the overall computational grid for a case without a base cavity. The grid is projected on two planes for simplification, even if the total grid and computations were performed in three dimensions. The 3-dimensional calculations were required since the flowfields produced by the projectile at incidence have only planar symmetry (only at zero incidence can axial symmetry be exploited). However, only half of the full geometry of this

[1] TASCflow™ is a registered Canadian trademark of ASC Ltd.

problem needed to be resolved, since its symmetrical characteristics. Figure 7 shows an expanded view of the computational grid in the base region for the case with a shallow cavity.

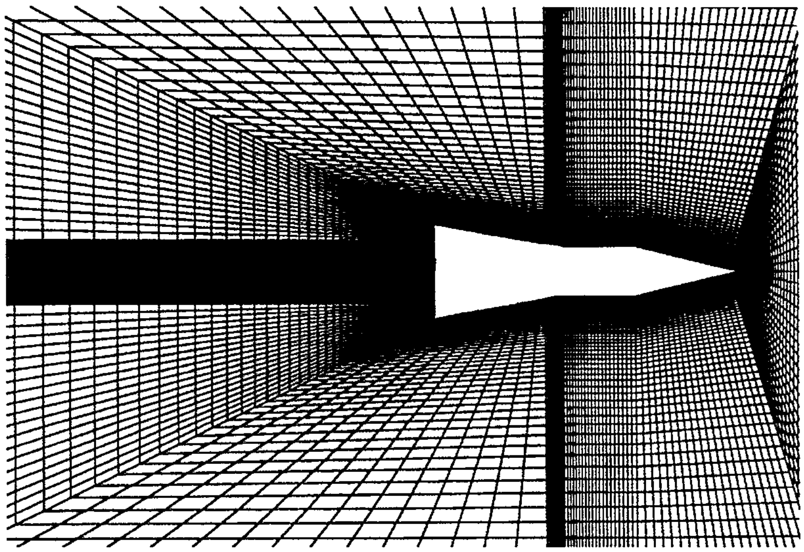

FIGURE 6 - Overall computational grid for a projectile without a cavity

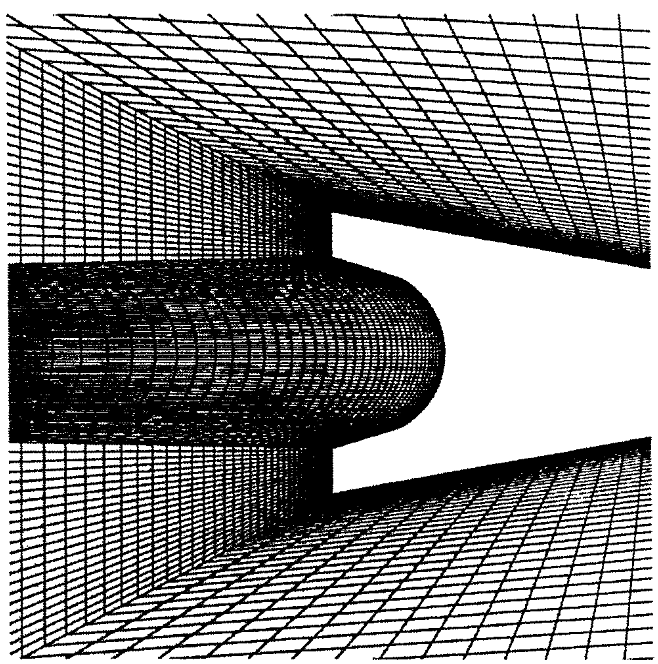

FIGURE 7 - Computational grid for a projectile with a shallow cavity (base region only)

The resulting grid (for all cases tested) contained 189000 nodes (distribution: 150 x 60 x 21), distributed following various patterns depending on the requirements of the specific cases tested. This grid was assumed sufficient to prevent shock wave reflection off the outer boundary and hence possible downstream interference, as well as to ensure full supersonic flow at the outflow boundary (grid selected following a sensitivity analysis to determine the grid size required for a grid independent solution). The applied boundary conditions for the cases studied in this analysis included a range of Mach numbers from 3.5 to 5.75 for turbulent flows (k-ε turbulence model: turbulence intensity of 0.1 with eddy length scale of 7.8×10^{-3}). Standard sea level pressure and temperature were employed (p=101325 Pa, T=293.15 K). These conditions are summarized in Table I.

TABLE I

DREV simulations flight parameters

Mach number	3.5 to 5.75
Pressure (N/m^2)	101325.1
Temperature (K)	293.15
Velocity (m/s)	1190 to 1955
Re/m	91.3×10^6 to 150.2×10^6

5.0 RESULTS

A test program consisting of seven firings (three around a Mach number of 4.5, and four around a Mach number of 5.75) of the CAN-4 projectile was conducted during the summer of 1995 in DREV's aeroballistic range. In an attempt to confirm some experimental results gathered from the literature (Ref. 1), some of these projectiles were fired with a base cavity (4), and others (3) with the base cavity closed.

Figure 8 shows the pitching moment coefficient slope ($C_{M\alpha}$), for all seven cases fired. From these results, the value of $C_{M\alpha}$ (about -5.1) seems to be very constant over the range of Mach numbers studied. Also, the effect of the base cavity seems to be negligible on the value of $C_{M\alpha}$. No significant effects on the drag coefficient were identified in this experiment.

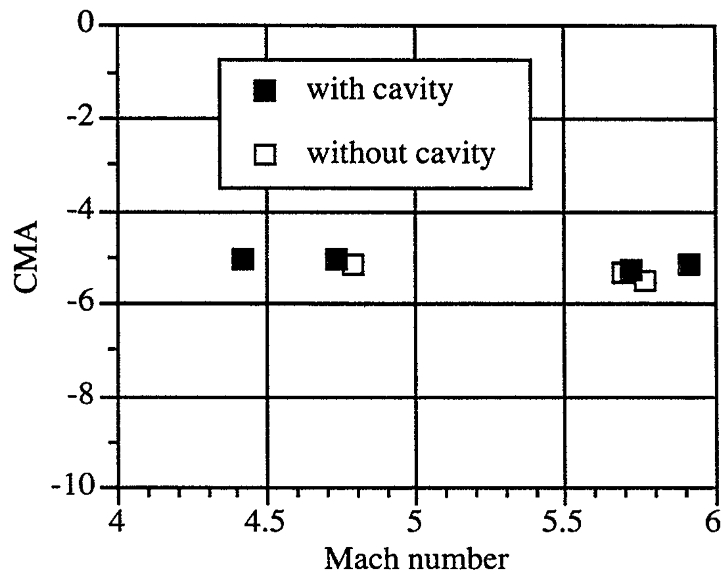

FIGURE 8 - $C_{M\alpha}$ for CAN-4 (experimental)

However, the trends shown by these results do not correspond to the results observed in other investigations (Refs. 1-4), which were presented in the background section. Thus, in order to provide additional information and substantiate the A/B range results, a complete CFD investigation on the nature of the flow in the wake of a projectile, with and without a base cavity, was initiated. This computational study covered a wide range of test conditions: four different Mach numbers (3.5, 4.5, 5.0, and 5.75), three base cavity depths (0.72, 1.44, and 2.12 calibres), and also the closed base case.

5.1 Aerodynamic Information

Tables II and III, and Fig. 9 provide a summary of the aerodynamic coefficient calculations performed for these cases. Values at only two Mach numbers, 4.5 (Table II) and 5.75 (Table III), were included in these results, as these correspond to the results available from the aeroballistic range values.

TABLE II

Results at Mach 4.5

Experimental	C_X	C_{XB}	$C_{M\alpha}$	$C_{N\alpha}$
no cavity	0.653	--	-5.174	7.080
38.12 mm cavity	0.646	--	-5.086	7.000
CFD	C_X		$C_{M\alpha}$	$C_{N\alpha}$
no cavity	0.662	0.234	-5.152	6.929
13.0 mm cavity	0.671	0.227	-5.207	6.920
26.0 mm cavity	0.646	0.235	-5.141	6.917
38.12 mm cavity	0.638	0.229	-5.167	6.903

TABLE III

Results at Mach 5.75

Experimental	C_X	C_{XB}	$C_{M\alpha}$	$C_{N\alpha}$
no cavity	0.544	--	-5.499	7.000
38.12 mm cavity	0.537	--	-5.209	7.100
CFD	C_X		$C_{M\alpha}$	$C_{N\alpha}$
no cavity	0.529	0.148	-5.440	6.884
13.0 mm cavity	0.527	0.144	-5.377	6.867
26.0 mm cavity	0.537	0.146	-5.629	6.742
38.12 mm cavity	0.538	0.145	-5.318	6.730

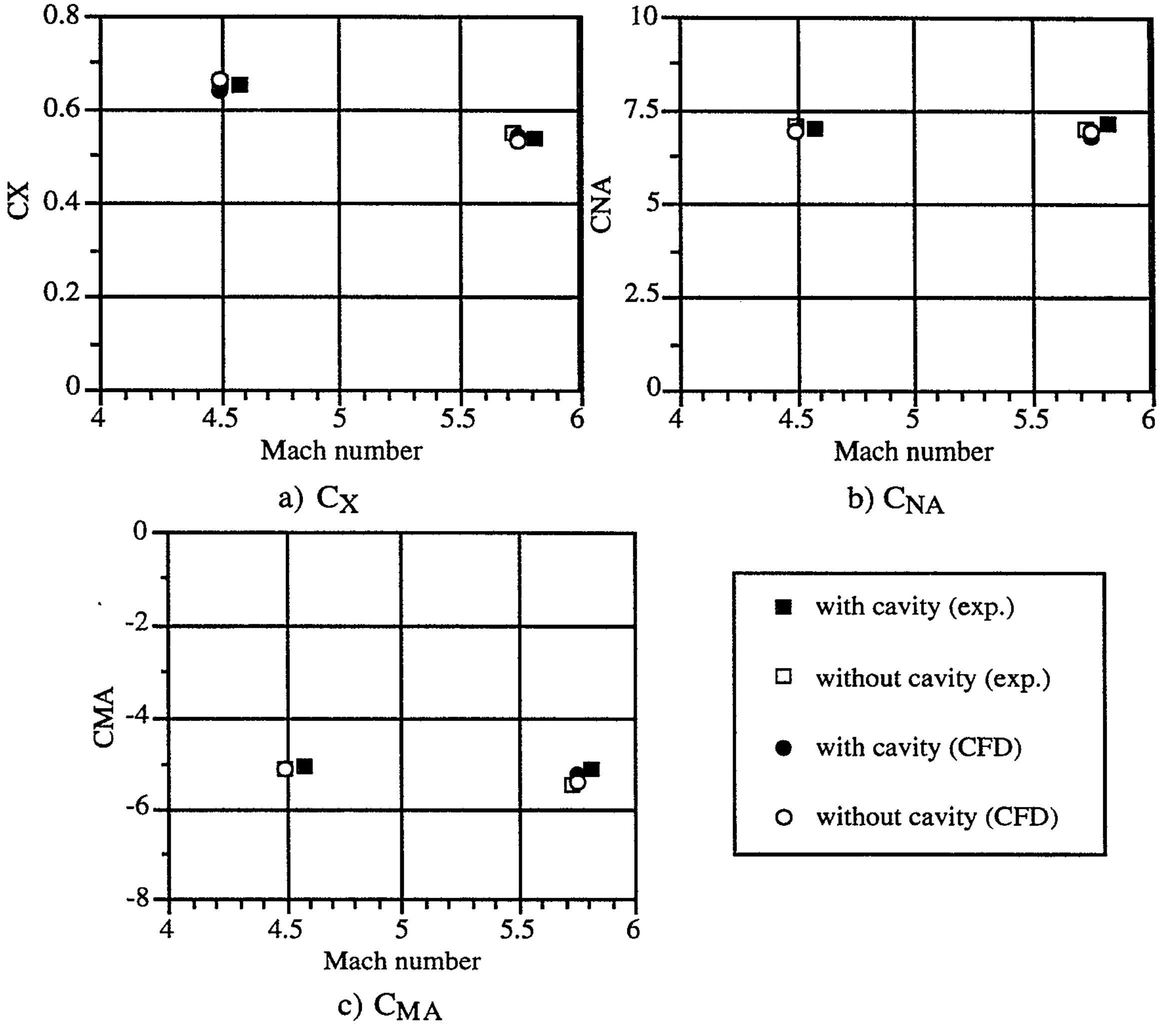

FIGURE 9 - Aerodynamic coefficients for CAN-4

The experimental values for these three aerodynamic coefficients were calculated from a multiple likelihood method fit through the results of several individual firings. They carry a probable error of less than ± 2.0% for $C_{N\alpha}$, while the errors for C_X and $C_{M\alpha}$ were less than ± 1.0%. It should be noted that small variations (less than 3%) exist between the experimental values measured with and without a base cavity. However, these variations were mostly produced by small variations in the flight Mach number for each case calculated, and are probably not directly related to the presence of a cavity on the projectile.

With a maximum relative error between the experimental and computational values of around 4% (for C_X at Mach 4.5) and a minimum relative error of 0.25% (for $C_{M\alpha}$ at

Mach 4.5), it can be concluded that the CFD calculations succeeded in predicting these coefficients in a satisfactory manner.

Some interesting results and comparisons are provided by the lack of a substantial difference between cases with and without a base cavity. Neither drag nor pitching moment (or normal force) slopes seemed affected by the presence of a base cavity. The absence of an observable effect on the aerodynamic coefficients seems to indicate a totally different relation between these coefficients and the presence of a cavity, when compared with the conclusions reached by Celmins (Ref. 1) and Sahu (Ref. 4). However, the model used by Sahu to conduct his CFD analysis was subjected to reduction of the projected area of the cavity, while the changes of configuration for the present experiment only consisted in increasing the cavity's depth, while maintaining the frontal area of the cavity constant.

Several other aerodynamic coefficients were obtained experimentally (pitch damping, etc.), but were not used in the comparison process. A method to calculate one of the dynamic coefficients (pitch damping: C_{MQ}) from CFD results (Ref. 10) is now being implemented at DREV, but was not used in this study. The cubic pitch moments were however compared. The cubic pitch moment coefficient, $C_{M\alpha^3}$ (Ref. 5), was reduced experimentally to -45.0 at Mach 4.5. CFD calculations were conducted at various angles up to 10° angle of attack and the pitching moment coefficient (C_M) is shown in Fig. 10.

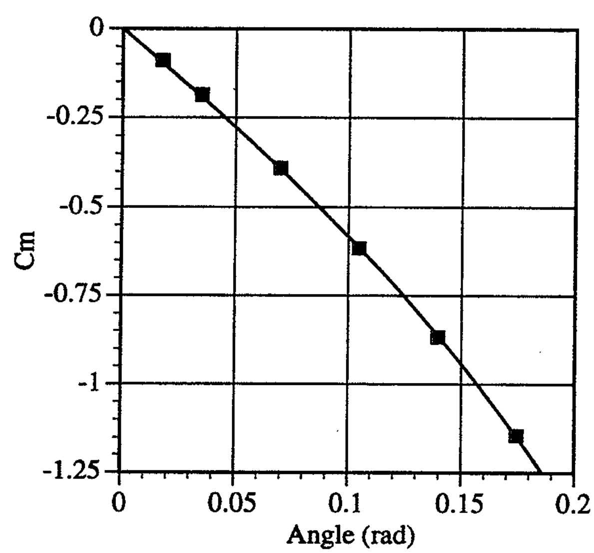

FIGURE 10 - C_M versus angle of attack

From curve fitting, the value calculated ($C_{M\alpha^3}$ (Ref. 5)) from the simulated results is approximately -39.5. A relative error of around 12.5% exists between these two values. It should be understood that this coefficient is a non-linear coefficient, which tends to present added difficulties for a numerical prediction. Thus, in view of the present results, it can be concluded that this variable is well determined by CFD, even if the result is not as precise as the previously calculated coefficients.

5.2 Base Flow Information

Case with solid base

Figures 11 and 12 show the solid base wake of the CAN4 projectile at Mach numbers 4.5 and 5.75, respectively. The CFD solutions showed the general features expected from this flow. A low pressure region is formed immediately downstream of the base, which is characterized by a low speed recirculating flow region (elliptical shape). It should also be noted that the expected velocity defect in the wake can also be seen further downstream in both figures. In the recirculation region, the flow starts from the stagnation point, accelerates towards the base of the model, slows down to a low subsonic velocity close to the model, and finally turns upwards to develop the recirculation.

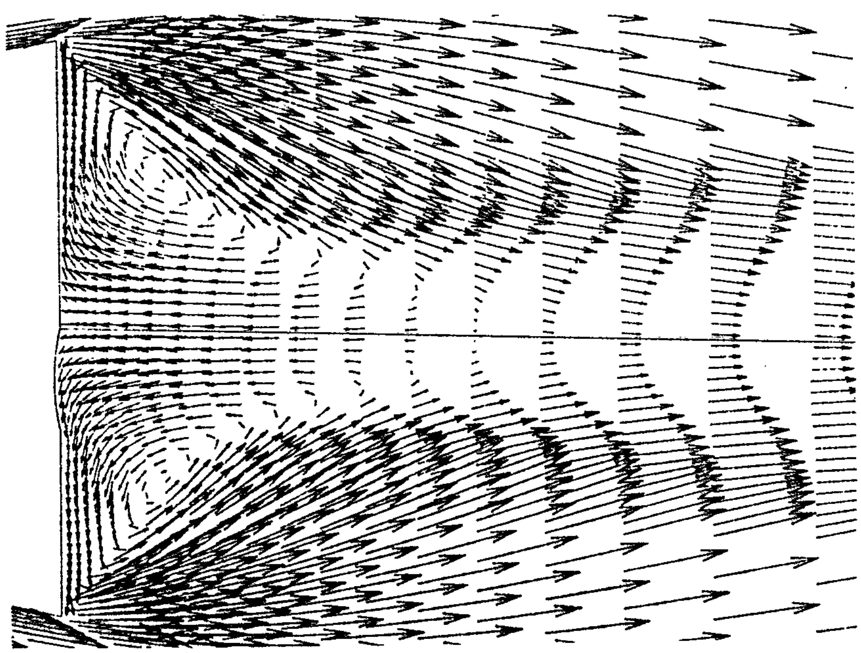

FIGURE 11 - Near wake of solid base (Mach 4.5)

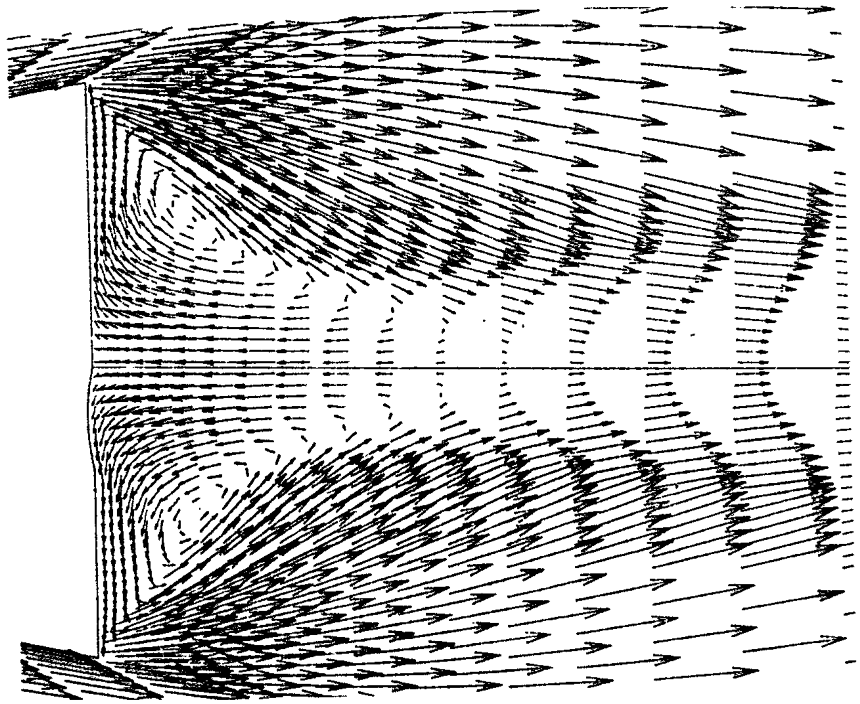

FIGURE 12 - Near wake of solid base (Mach 5.75)

As the results for this section are only computational (the A/B range only provides aerodynamic coefficients and shocks structure), there exists a requirement to validate or correlate these results with some from experimental sources. Parker Lamb and Oberkampf (Ref. 11) have performed a comprehensive review of experimental base pressure data, and have constructed empirical based correlations for axisymmetric geometries up to hypersonic flows. Using their results for a turbulent cone with a half angle of 10°, it was possible to correlate the base pressure results, even if CAN-4 is more than just a simple cone. Figure 13 shows a reproduction of their correlation curve for a turbulent cone, with the present results shown as data points. The quantity used for the vertical axis is calculated from the base pressure, while the quantity used for the horizontal axis is derived from the Mach number (Crocco number). For the four Mach numbers calculated, the trend demonstrated by the CFD curve corresponds well to their results. The difference between the two curves is probably produced by the fact that CAN-4 is not a simple cone, but a complete cone-cylinder-flare projectile.

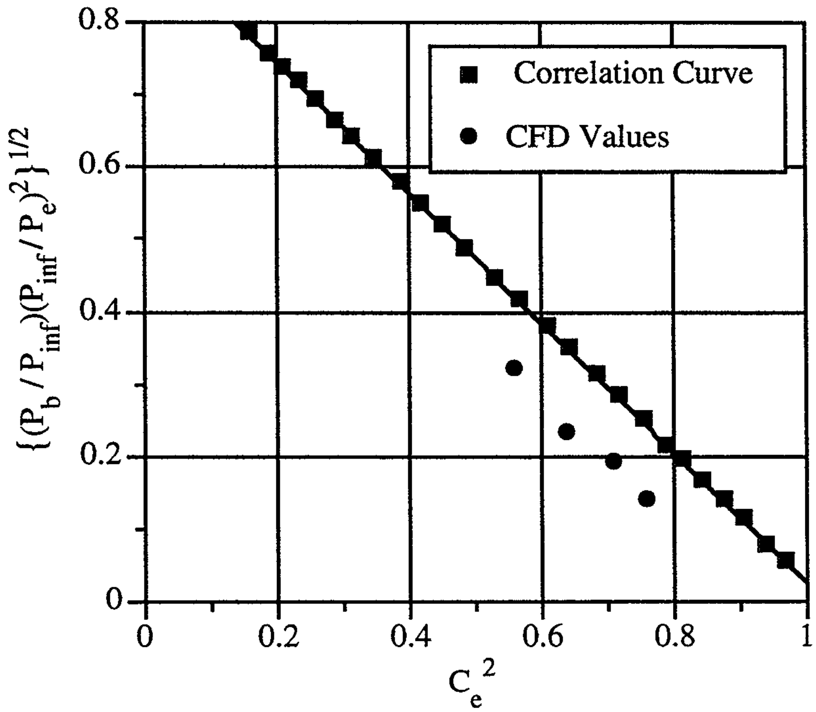

FIGURE 13 - Correlation of base pressure for turbulent flow past cones of various angles

Additional information about the recirculation zone can also be gathered from the literature. The recirculation region extended to about 0.75 base diameter of the base corner (given by the change in direction of centreline velocity) for these two cases (a little shorter for the higher Mach number). These results compare well with the results provided in an experiment (cone at Mach 6.0) by Martellucci *et al.* (Ref. 12).

Finally, the centreline static pressure variation downstream of the body will be examined in the following section as experimental values exist to validate the present CFD calculations.

Case with base cavity

As mentioned previously, flow simulations with three different base cavities (affected parameter: cavity depth) were performed for several inflow Mach numbers. Figure 14 shows velocity vectors in the base area of the medium cavity (depth of 1.44 calibres) for a Mach number of 4.5.

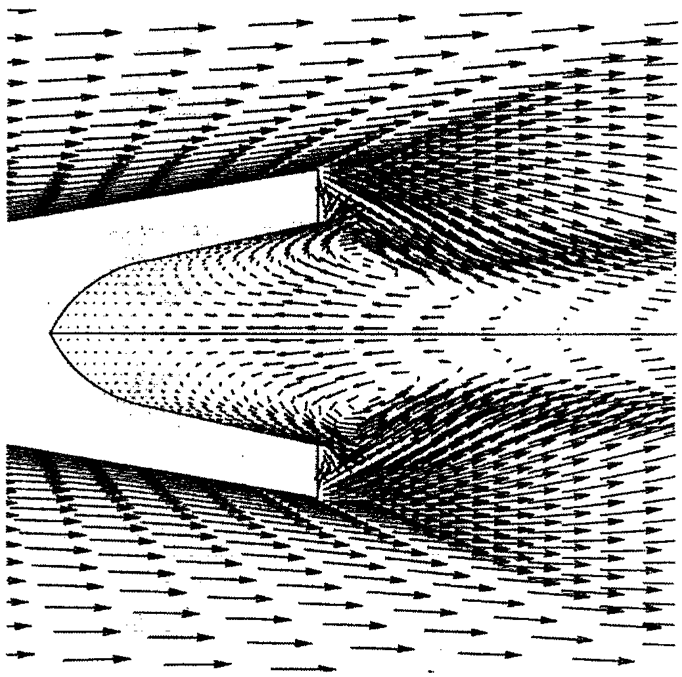

FIGURE 14 - Near wake of medium cavity base (Mach 4.5)

Many features are identifiable on this figure. First, the recirculatory flow in the base region is evident, as it extends in the cavity itself. Then, two flow expansions are apparent, one at the end of the flare section, and the other one at the end of the cavity (see Fig. 14 for additional information). This second expansion is generated by the back flow, which on reaching the end of the cavity, follows the contour of the cavity, and leaves the cavity in the same direction as the freestream flow. The end of the recirculation region gives the location of the stagnation point. This stagnation point signals the most downstream position of the recirculation zone, which extends to about 0.83 base diameter of the base corner, and is given by the change in direction of the centreline velocity. It should be noted that the presence of the cavity does not seem to have a large effect on the downstream position of the stagnation point (from base plane, not cavity depth) as the stagnation point for the solid base case was around 0.75 base diameter of the base corner.

A final feature to be identified on this figure is the presence of secondary recirculation zones, which were not present for the solid base case. One is positioned on the back surface of the projectile, at the intersection with the cavity. The effects of these additional recirculation zone on the flow around the projectile have not been investigated, and are mostly unknown.

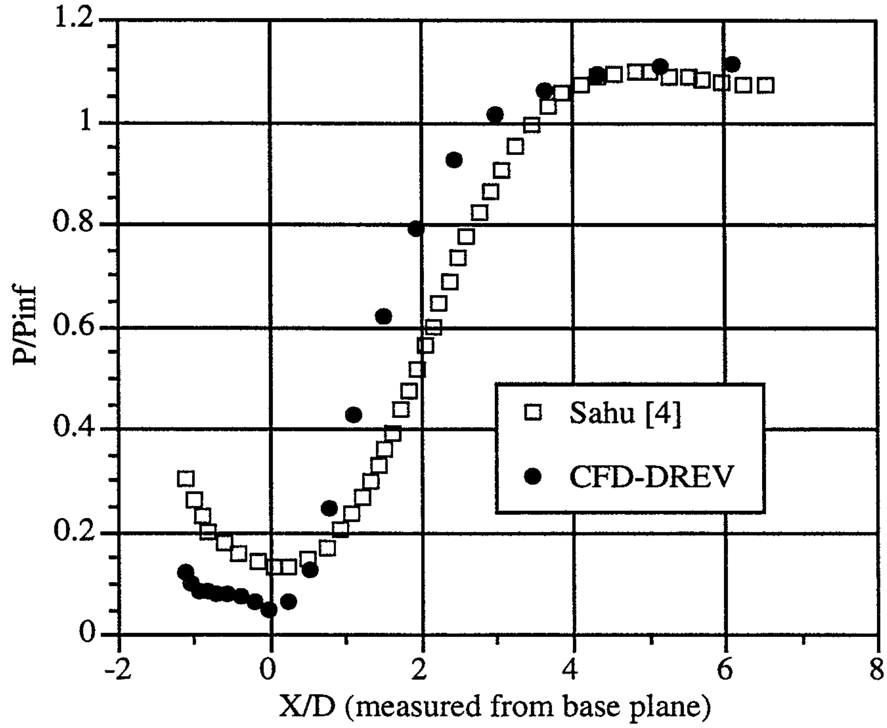

FIGURE 15 - Wake centreline pressure distribution (Mach 4.5)

One of the quantitative comparisons that can be made with these results consists in looking at the static pressure distribution along the centreline in the recirculation zone. Figure 15 shows an example of this type of curve, and provides comparison with another set of numerical values. The results, compared with the results from Ref. 4, present a generally good agreement. The ratio P/P_∞ initially decreases with increasing distance (inside of the cavity) to reach a minimum value on the base plane (approximately), then increases rapidly to a peak pressure that is somewhat larger than P_∞, and finally overexpands towards P_∞.

6.0 CONCLUSIONS

The aerodynamics of a cone-cylinder-flare projectile, with various base cavities and flying at high supersonic speeds has been investigated through experimental and computational means. Aerodynamic coefficients, base pressure surveys, and base flow visualization over this projectile were investigated. Comparisons were carried out between the results originating from the different sources. Good agreement resulted from most of the comparisons with experimental values or other CFD results.

Correlations between experimental and the present numerical values seem to indicate an independence between the aerodynamic properties and the presence of a base cavity for this particular configuration. This was demonstrated by the lack of significant differences between aerodynamic coefficients calculated from different sources.

7.0 RECOMMENDATIONS

It is recommended that additional work be performed on the base cavity concept:

- to allow for some comparisons with the results from Ref. 4, numerical simulations with different base cavity arm thicknesses would be required (changes in base cavity opening dimensions).

8.0 ACKNOWLEDGEMENTS

We would like to acknowledge the assistance of Dr. J. Edwards of DRA for his assistance during this study.

9.0 REFERENCES

1. Celmins, I., "Drag and Stability Tradeoffs for Flare-Stabilized Projectiles," AIAA Paper No. 90-0065, 28th Aerospace Sciences Meeting, Reno, Nevada, USA, January 8-11, 1990.

2. Compton, W.B., "Effect on Base Drag of Recessing the Bases of Conical Afterbodies at Subsonic and Transonic Speeds," NASA Technical Note D-4821, October 1968.

3. Nash, J.F., Quincey, V.G. and Callinan, J., "Experiments on Two-Dimension Base Flow at Subsonic and Transonic Speeds," Aeronautical Research Council Report #3427, London, 1966.

4. Sahu, J., "A Computational Study of the Base Region Flow Field for the M865 projectile," Army Research Laboratory Report ARL-TR-109, April 1993.

5. Dupuis, A. J. and Edwards, J., "Aerodynamic Characteristic of the CAN4 Hypersonic Research Configuration from Free-Flight Tests," DREV-TM-9525, February 1996, UNCLASSIFIED

6. Dupuis, A. and Drouin, G., "The DREV Aeroballistic Range and Data Analysis System," AIAA Paper No. 88-2017, 15th Aerodynamic Testing Conference, San Diego, California, USA, May 18-20, 1988.

7. "Ballistic Range Data Analysis System (BARDAS)," Arrow Tech Associates Inc., DREV Contract No. W7701-0-1227, March 1992.

8. Dupuis, A. D., Edwards, J. A. and Normand, M., "Aerodynamic Characteristic and Aeroheating Aspects of Two Hypersonic Configurations from Free-Flight Tests," DREV-R-9428, October 1995, UNCLASSIFIED

9. "TASCflow - Version 2.4 : Theory and User Documentation," ASC Advanced Scientific Computing Limited, Waterloo, Ontario, Canada (03/1995).

10. Qin, N., Ludlow, D. and Shaw, S., "Calculation of Pitch Damping Coefficients using the PNS Equations in a Non-inertial Framework," Cranfield University, College of Aeronautics Report 9601 NFP, Cranfield, 1996.

11. Parker Lamb, J. and Oberkampf, W.L., "Review and Development of Base pressure and Base Heating Correlations in Supersonic Flow," Journal of Spacecraft and Rockets, Volume 32, Number 1, January-February 1995.

12. Martellucci, A., Trucco, H. and Agnone, A.,"Measurements of the Turbulent Near Wake of a Cone at Mach 6," AIAA Journal , Volume 4, Number 3, March 1966.

INTERNAL DISTRIBUTION
DREV - TM - 9620

1 - Deputy Director General
1 - Head, Delivery Systems Section
6 - Document Library
1 - E. Y. Fournier (author)
1 - A. D. Dupuis (author)
1 - F. Lesage
1 - B. Girard
1 - A. Jeffrey
1 - G. Drouin
1 - R. Delagrave
1 - G. Bérubé
1 - P. Twardawa

EXTERNAL DISTRIBUTION
DREV - TM - 9620

2 - DRDIM
1 - CRAD
1 - DSAL
1 - DLR
1 - DAR (FT)
1 - DSAA
1 - DSAM
1 - DAEPM(FT)
1 - DRES

4 - Dr. J. Edwards
(2 for further UK distribution)
1 - Mr. C. Hilderbrands
1 - Mr J. J. Roper
DRA Military Division
Fort Halstead
Sevenoaks
Kent TN14 7BP
England

1 - Dr. C. Berner
Institut franco-allemand de recherches
5, rue du Général Cassagnou
B. P. 34
68301 - Saint-Louis
France

1 - Dr. B. J. Walker
AMSMI-RD-SS-AT
Commander
U. S. Army Missile Command
Redstone Arsenal, AL
35898-5252

1 - Dr. P. Plostins
SLCBR-LF-F
Army Research laboratory
Aberdeen Proving Ground
Maryland 21005-5066
USA

1 - Mr. A. J. Sadler
Head AP6
Weapons Aerodynamics Division
DRA
Bedford MK41 6AE
England

1 - Dr. J. Gardner
DSTO
Surveillance Research Laboratory
P.O. Box 1500
Salisbury, SA 5108
Australia

1 - Dr. K. Krishnamoorthy
DSTO
Weapons Systems Division
P.O. Box 1500
Salisbury, SA 5108
Australia

UNCLASSIFIED

1 - Dr. P. Sullivan
University of Toronto
Institute for Aerospace Studies (UTIAS)
4925 Dufferin St.
Downsview, ON
M3H 5T6

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM
(Highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA

1. ORIGINATOR (name and address) DREV	2. SECURITY CLASSIFICATION (Including special warning terms if applicable) UNCLASSIFIED

3. TITLE (Its classification should be indicated by the appropriate abbreviation (S,C,R or U)
COMPUTATIONAL FLUID DYNAMIC ANALYSIS OF THE BASE CAVITY INTERACTIONS OF THE CAN-4 RESEARCH PROJECTILE

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

FOURNIER, ERIC Y., DUPUIS, ALAIN, D.

5. DATE OF PUBLICATION (month and year)	6a. NO. OF PAGES	6b. NO. OF REFERENCES
MARCH 1997	24	12

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. Give the inclusive dates when a specific reporting period is covered.)

MEMORANDUM, JULY 95-MAY 96

8. SPONSORING ACTIVITY (name and address)

9a. PROJECT OR GRANT NO. (Please specify whether project or grant) 2EA19	9b. CONTRACT NO.
10a. ORIGINATOR'S DOCUMENT NUMBER TM-9620	10b. OTHER DOCUMENT NOS. N/A

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

- [X] Unlimited distribution
- [ ] Contractors in appoved countries (specify)
- [ ] Canadian contractors (with need-to-know)
- [ ] Government (with need-to-know)
- [ ] Defence departments
- [ ] Other (please specify) :

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

UNLIMITED

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM

UNCLASSIFIED

SECURITY CLASSIFICATION OF FORM

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

The aerodynamics of a cone-cylinder-flare projectile at high supersonic speeds has been investigated through computational means, and the results compared with existing experimental results. Aerodynamic coefficients, base pressure surveys, base flow visualization and shock patterns over the projectile were investigated for a Mach number range of 3.5 to 5.75. A goal of this investigation was the numerical study of the effects of a base cavity on the aerodynamic behavior of this projectile. Quantitative and qualitative information was accurately modelled by the CFD code as indicated by correlations between experimental and numerical values. The results seem to indicate an independence between the aerodynamic coefficients (aerodynamic coefficients constitute some of the major parameters of this study) and the presence of a base cavity for this particular configuration.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each sould be indicated as with the title.)

AERODYNAMIC COEFFICIENTS
DRAG
HYPERSONIC
CFD
AEROBALLISTIC RANGE

UNCLASSIFIED

SECURITY CLASSIFICATION OF FORM

Requests for documents
should be sent to:

DIRECTOR SCIENTIFIC INFORMATION SERVICES
Dept. of National Defence
Ottawa, Ontario
K1A 0K2
Tel: (613) 995-2971
Fax: (613) 996-0392

S01873

Toute demande de document
doit être adressée à:

DIRECTEUR - SERVICES D'INFORMATION SCIENTIFIQUE
Ministère de la Défense nationale
Ottawa, Ontario
K1A 0K2

Téléphone: (613) 995-2971
Télécopieur: (613) 996-0392